An Assessment of the United States Measurement System:

Addressing Measurement Barriers to Accelerate Innovation

Appendix F

The Methodology of the Inferential Analysis

NIST Special Publication 1048

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

U.S. Measurement System

The Approach Used to Infer the State of the USMS from the MN Analysis, Roadmap Analysis, and USMS Characterization

Prepared by
Energetics Incorporated
for the
National Institute of Standards and Technology

June 2006

The Approach Used to Infer the State of the USMS from the MN Analysis, Roadmap Analysis, and USMS Characterization

Table of Contents

List of Exhibits

The Approach Used to Infer the State of the USMS from the MN Analysis, Roadmap Analysis, and USMS Characterization

Background

The United States Measurement System (USMS) is a complex system of interconnections among diverse scientists, technologists, companies, and organizations that develop and supply methods, data, instruments, and standards involved in making measurements that are vital to the U.S. economy, security, and quality of life. Accurate measurements are pervasively important throughout society. An effective measurement system enables technology innovation and strengthens competitiveness; supports strong national security and defense; and facilitates the protection of health, safety and the environment.

In our technology-driven economy, scientific breakthroughs and innovation foster the continual development of new technologies, processes and products. As these emerge, new measurement challenges are often created. To ensure that the USMS can keep pace with technological advancement and meet future measurement needs, the National Institute of Standards and Technology (NIST) assessed the state of the USMS. The assessment focused on measurement needs where the lack of measurement capability constitutes a significant barrier to technological innovation.

Summary of Methodology

The measurement needs identified in published roadmaps (RMNs) and in the measurement need case studies submitted by NIST and industry (referred to as measurement needs—MNs) were used as a proxy of the measurements needed for technology innovation that exist in the economy. An inferential analysis based on these measurement needs, a characterization of the USMS, and published information were conducted as outlined in this document. The completed inferential analysis was used to determine the state of the USMS.

The inferential analysis was based on

- An analysis of measurement needs from the roadmaps and individual MNs
- Knowledge of the USMS
- Characterization of the USMS
- Published information and data

Data-driven Analysis of Measurement Needs

A data-driven analysis of measurement needs was based on roadmaps and measurement needs as presented in Exhibit 1. First, 200 published science and technology roadmaps were reviewed. Roadmaps cover diverse areas, from materials to first responders and transportation. Over 87 percent of the roadmaps reviewed identified measurement needs. The roadmap measurement needs (RMNs) were analyzed and summarized in the document *NIST USMS Technology Roadmap Review* (2006). This analysis includes all the RMNs as well as RMN subsets. Trends in measurement needs as well as commonalities across sectors and processes/products were identified. The roadmaps and documents reviewed are listed in Appendix A of the *NIST USMS Technology Roadmap Review* (2006). This document was used as the RMN Rollup Analysis, an important input to the inferential analysis.

Second, MNs were developed from the perspectives shown in Exhibit 2 using a pre-defined template. These include measurements that are specific to industrial sectors, individual technologies, scientific disciplines, and physical properties. There are over three hundred MNs.

Exhibit 1. Data-Driven Analysis of Measurement Needs

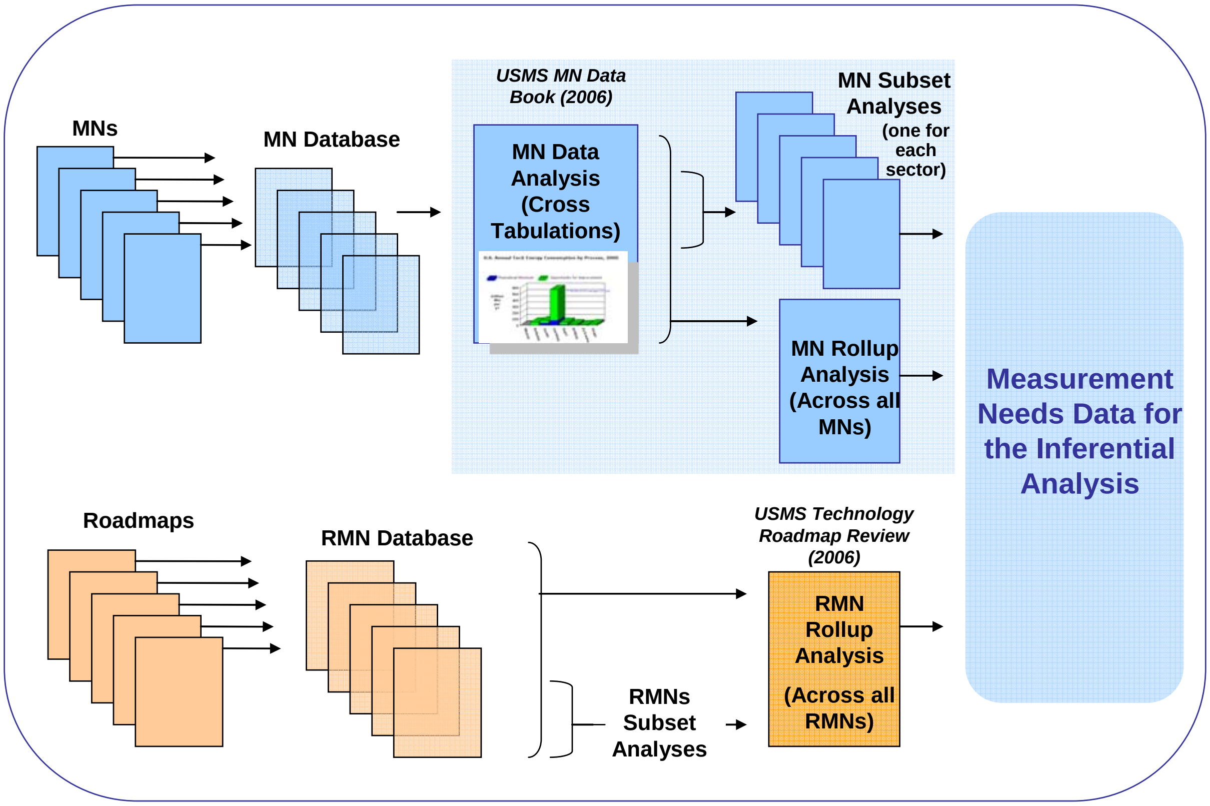
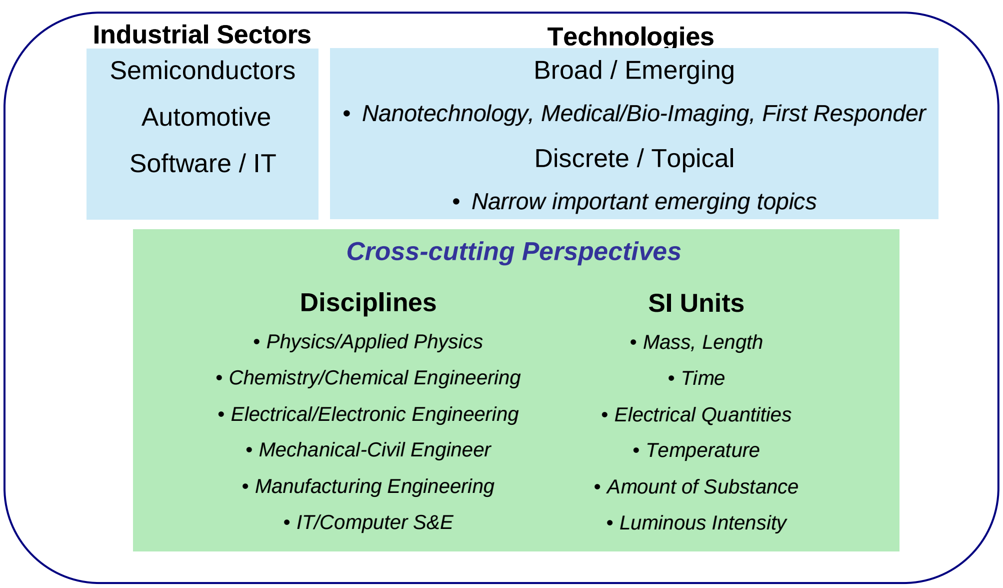


Exhibit 2. Measurement Needs (MN) Assessed with Template



Each MN was "tagged" according to the categories in Exhibit 3 and the results were entered into a MN database. A MN data analysis was conducted based on all the MN Tags and documented in the *USMS Measurement Need (MN) Data Book* (2006). The MN data analysis has two parts: MN Subset Analyses and the MN Rollup Analysis (across all the MNs). The MN data analysis was an important input to the inferential analysis.

Exhibit 3. MN Analysis Categories			
#	**Categories**	**Tags**	**Information Gained**
1	**NIST Economic Sectors/Technology Area (M)**	• Agriculture and Food Processing • Building and Construction - Residential / Commercial Building - Civil Infrastructure • Chemicals • Defense • Electronics - Semiconductor - Non-semiconductor • Energy and Power - Fossil fuel - Hydrogen - Renewable - Power Generation and Distribution - Nuclear • Environment • Healthcare - Bioimaging and Informatics - Clinical Diagnostics - Health and Safety - Pharmaceuticals • Homeland Security - First Responders • Industrial Biotechnology • Information Technology - Software - Hardware • Manufacturing - Discrete - Continuous • Materials - Ceramics - Metals - Polymers • Measurement Technology - Instrumentation - Process Control - SI Units • Nanotechnology • Telecommunications • Transportation - Aerospace - Automotive • Other—Law Enforcement • Other	What sectors have measurement needs
2	**NAICS (M)**	• TBD--Three-six digit (NIST to provide)	Sectors with identified needs; Map to roadmaps
3	**NIST Basis**	• Automotive • Semiconductors • Software • SI Units - Length	

Exhibit 3. MN Analysis Categories			
#	**Categories**	**Tags**	**Information Gained**
		- Time - Mass - Electric current - Temperature - Amount - Luminous intensity • Discipline - Physics/Applied Physics - Chemistry/Chemical Engineering - Materials Science/Engineering - Electrical/Electronic Engineering - Mechanical/Civil Engineering - Computer Science/Engineering - Manufacturing Engineering • Technology - Nanotechnology - Biomedical Imaging - First Responders - Discrete	
4	**Stage of Technology Innovation**	• Applied Research • Production • Market • End-Use	Distribution of needs among stages of technology innovation
5	**Is the Technological Innovation at Stake a Measurement Technology?**	Yes/no	What is leading edge of measurement innovation
6	**Regulation is a Driver or Barrier**	Driver? Yes/no Barrier? Yes/no	
7	**Effort in Progress (M)**	• Are there any known Public efforts? Yes/no • Are there any known Private Efforts? Yes/No	Identifies R&D gaps and gives insights on accessibility
8	**Measurand**	• Functional - Acoustical - Electronic/electrical - Magnetic - Optical - Photonic - Radio frequency - Thermal o Thermochemical o Thermodynamic o Thermophysical • Structural - Mechanical - Spatial - Kinetic - Molecular • Classical - Biological - Chemical - Physical - Physiological • Performance - Computational Performance	Property/attribute categories of measurement needs

Exhibit 3. MN Analysis Categories			
#	**Categories**	**Tags**	**Information Gained**
		- Software Performance - System Performance	
9	**Measurement Solution Barriers (M)**	- Expense - Production readiness - Reliability - Speed - Accuracy - Resolution - Destructive - Acceptability/compatibility - Data, data collection and/or retrieval - Workforce - Accessibility - Multiple solutions exist - Small market demand - System-level problem - Lack of fundamental knowledge - Not standardized	Kinds of challenges currently faced in technology innovation
10	**Measurement Solution (Product/ Service/ Infrastructure) (M)**	• Products - Measurement instrument - Measurement method - Software - Computational method or models (validated) - Calibration method - Raw properties data - Validated (hardened) properties data - Test methods for production-scale measurements - Test methods or test data for consumer products - Standard/certified reference material - Stability tests (interim check stand) - Reference data - Metrics / Benchmarks • Services - Calibration service - Expert consultation - Third-party verification/validation - International recognition • Infrastructure - Data collection and retrieval systems - Standards - Protocols - User facility - Coordination/facilitation - Fundamental scientific knowledge - Research for measurement science - Development for measurement technology	Type of products that are needed/needed most often
11	**Potential Solution Providers (M)**	• National Measurement Institute • Government laboratories and agencies • Independent testing/certification laboratories • Calibration laboratories • Commercial calibration service providers • Testing laboratories • Contractor R&D labs-for-hire • Universities • Software developers • Industrial R&D laboratories	Incidence of providers needed

Exhibit 3. MN Analysis Categories			
#	Categories	Tags	Information Gained
		• Small business/inventors • Instrument suppliers • Component suppliers • Material suppliers • Standards development organizations (SDO) • Engineering management/consulting firms/A&E firms • Industry consortium/partnership	

Exhibit 4 provides examples of queries and cross tabulations that were conducted and included in the MN data analysis. Most of this information was presented in stacked bar graphs. Each MN category may have more than one "tag"(except for categories # 4, 5, 6, and 7) and each tag was represented by one "slice" of a stacked bar. The same queries were conducted for the subsets, and the results were compared to the MN rollup analysis (i.e., to determine how the subset is different from the whole). Subsets of the NIST Economic Sectors/TechnologyAreas that are listed in Exhibit 3, Category #1 were reviewed for the inferential analysis.

As shown in Exhibit 1, the measurement needs data for the inferential analysis was based on the RMN Rollup Analysis, the MN Rollup Analysis, and the MN Subset Analyses. The RMN Database and the MN Database were also available as a resource. The information available for the MNs and RMNs is shown in Exhibit 5. The MN database included potential measurement solution providers for each MN as well as other information that is not available from the roadmaps. Consequently, additional analysis on the MN dataset was feasible.

Exhibit 4. Examples of Queries and Cross Tabulations for the MN Data-Driven Analysis

The following numbers refer to categories listed in Exhibit 3.

1. **Distribution of MNs in each category**: Rollup distribution for all categories (#1-11) across MNs (i.e., number of MNs by sector (#1), number of MNs by measurand (#8), etc).

2. **Commonalities and synergies across sectors:** For each sector (#1), into what stage of technology innovation (#4) do the measurement needs fall? What percentage of MNs is for measurement innovation (#5)?

3. **Commonalities and synergies across measurement solutions (as a representation of measurement needs):** For each type of measurement solution (#10), what potential solution providers (#11) could be involved? What measurement barriers (#9) have to be overcome? What types of efforts are in progress (#7)? What types of measurands (#8) are needed?

   For each type of potential solution provider (#11), what efforts are in progress (#7)? What measurands (#8) are they focused on most often?

4. **Other patterns in measurement:** For each measurand (#8), what measurement solutions (#10) are identified most often? What measurement barriers (#9) are identified most often? What is the distribution by stage of technology innovation (#4) and effort in progress (#7)?

5. **Other:** Identify and analyze other patterns from the collection of MNs and individual MNs.

Exhibit 5. Information Available for MNs and RMNs		
	MNs and/or MN Database Tags	Available in the Roadmap Analysis and/or Database Tags
1	NIST Economic Sectors/Technology Area	Yes
2	NAICS	Yes
3	NIST Basis	No
4	Stage of Technology Innovation	No
5	Is the technological innovation at stake a measurement technology	Yes, can be inferred
6	Regulation is a driver or barrier	Yes
7	Effort in Progress—Public and/or Private	No
8	Measurand	Yes, short list
9	Measurement Solution Barrier	No
10	Measurement Solution	No
11	Potential Solution Providers	No

Inferential Analysis to Develop Findings

The inferential analysis was conducted by diverse groups at NIST. The core group conducted an analysis based on all the measurement data. Other groups were assigned to analyze subsets of the data (see the NIST Economic Sectors/Technology Areas identified in Exhibit 3, category #1). Exhibit 6 provides an overview of the inferential analysis of measurement needs.

A series of facilitated workshops called the Inferential Analysis Café was held April 24 through May 2 in Gaithersburg, Maryland to analyze the data. The objective of the workshops was to derive some inferences about the USMS related to specific, selected sectors of the economy and important technology areas. In particular, it was hoped that a review of technology roadmaps and case studies describing measurement needs in these economic sectors/technology areas would give rise to a set of "findings" about how well the USMS is functioning. The emphasis was on measurement needs that could potentially be impeding technological innovation.

The week before the workshops, an overview of the workshop, the inferential analysis process, and the USMS characterization (see Appendix A) was provided to participants. The directions provided during this workshop are included in Appendix B.

The participants were given the data prior to the workshop. During the workshops, participants reviewed the data and worked in small groups to come up with a set of findings for their particular sector/technology area. A separate workshop was held following the sector-specific workshops to examine cross-cuts, synergies, and implications for the overall economy (within the subset studied for this exercise).

To develop their inferential analysis, each small group answered the questions listed in Exhibit 7. The workshop was organized by "rounds" which focus on specific tags used in the analysis of MNs (e.g., Measurement Barriers, Potential Solution Providers, etc.) as well as data found in technology roadmaps. Participants proceeded through a complete cycle of these "rounds" by the end of the day. The rounds are shown in Exhibit 8.

Each finding in the inferential analysis for the sector/technology areas and for the overall economy was documented by completing the Inferential Analysis Template that included the following information:

- **Focus Area/Factual Statement** – the facts used in developing the finding.
- **Interpretive Statement** – an interpretation of the facts presented.
- **Declarative Statement** – a more subjective interpretation, generally extending beyond what is factually stated to draw a conclusion which may need further analysis or data to verify.
- **Implications for the USMS** – what can be inferred for the USMS based on the factual statements and interpretations.
- **Question Parking Lot** – questions arising from the facts and interpretations that, if answered, would further clarify the finding.
- **Sources** – citations from the specific **Measurement Need Data Book**, **Technology Roadmap Review Report**, and other references

Published information and data was used to interpret the findings. After each small group completed their inferential analysis, the core group reviewed all the findings and assimilated them into a report.

Exhibit 6. Inferential Analysis of Measurement Needs

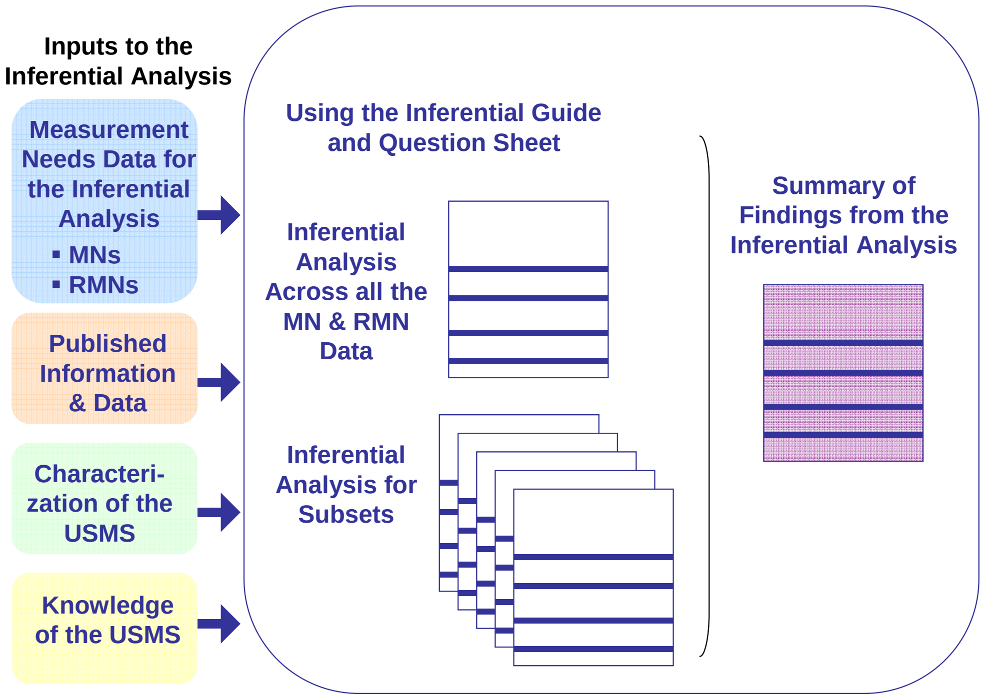


Exhibit 7. Agenda for the Inferential Analysis Café

Inferential Analysis Café for Sectors/Areas

April 26 & 27, 2006 • Marriott Washingtonian in Gaithersburg

Agenda

8:30 am Welcome & Introduction

Workshop purpose: Infer meaning from the spectrum of MN and RMN data for each sector/area(s)

8:45 am Overview of Today's Process

- Directions
- Overview of the Inferential Analysis Template (including Question Parking Lot)
- Understanding the Value and Limitations of the Measurement Need Data Sources
- Getting Started with the Analysis
- Steps
  - Rounds 1, 2, 3, 4, and 5 (see Exhibit)
  - Conclusions and guidance to reviewers
- Results—Consensus and Outcomes

9:00 am Round 1: Barriers, Providers, & Solutions

What inferences can be made from the distribution of barriers, providers, and solutions needed for the sector/area(s)? From the correlations between each of them?

10:15 am Break

10:30 am Round 2: Measurands, Effort in Progress, and Measurement Technology

What inferences can be made from the distribution and correlations between these elements and the barriers, providers and solutions?

11:30 am Round 3: Regulation and TI Stage of Development

What inferences can be made with respect to regulations as a barrier or driver for a measurement need considering the barriers, providers and solutions? What can be inferred from the technological innovation stage where the measurement needs are occurring?

12:15 pm Lunch

1:15 pm	Round 4: From the Technology Developer's perspective and Across Sectors/Areas *The sectors identified for each measurement need are a proxy of the technology developer's vision. What inferences can be made about the measurement needs especially with respect to barriers, providers, and solutions? What can be inferred from the measurement needs that exist across sectors/areas?*
2:00 pm	Round 5: Challenges to Measurement Innovation and USMS Operation *Based on the MN and RMN data, what challenges are hindering progress/success of measurement R&D and innovation? What can be discerned about how the USMS is functioning and the challenges that are faced? For example, when a measurement need arises as a barrier to technological innovation, the USMS may be functioning but a solution has not been found, or the USMS may not be functioning for a specific reason.*
2:45 pm	Break
3:00 pm	Conclusions and Guidance to Reviewers *What are your overall conclusions for the sector/area? What bias have you had throughout the day? What guidance can you provide to help reviewers?*
3:45 pm	Lessons Learned
4:00 pm	Adjourn

Exhibit 8. Progression of Data Analysis Through Rounds with Exhibit Number Reference for MN Data Book

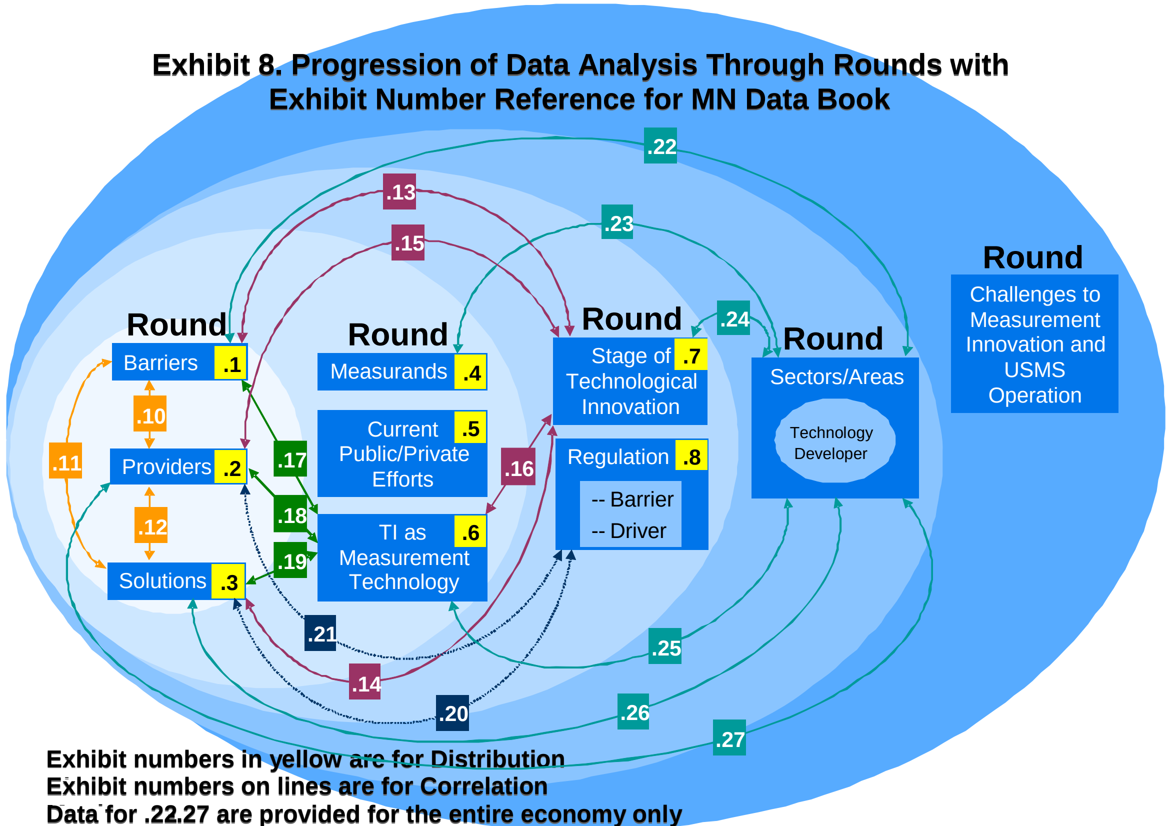
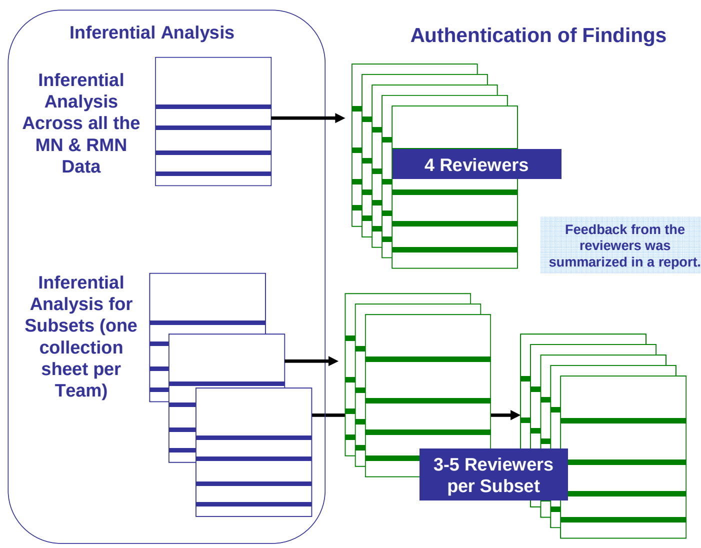


Exhibit numbers in yellow are for Distribution
Exhibit numbers on lines are for Correlation
Data for .22.27 are provided for the entire economy only
(colors are for distinguishing lines only)

Authentication of Inferential Analysis Findings

The inferential analysis findings from the workshops were subjected to a two-tier authentication process. Each reviewer reviewed one subset of the findings. A first set of findings, those that could be completely supported by data and analysis, were sent to external reviewers for "authentication," i.e., a review for sound judgment and reasonable conclusions. A second set of findings that were not entirely supported by fact or required additional investigation were also provided to external reviewers for comments. The feedback from the reviewers was analyzed and summarized in a report. Exhibit 9 provides an overview of the inferential analysis and authentication process. The inferential analysis and the authentication of findings were used to determine the state of the USMS with regard to promoting technological innovation. This was documented in a report.

Exhibit 9. Overview of the Inferential Analysis and the Authentication of Findings



APPENDIX A

Preliminary Characterization of the United States Measurement System (USMS)

Introduction

The U.S. Measurement System (USMS) is responsible for providing the accurate, reliable, and accepted measurements that are vital to R&D progress, commerce, and consumer interests throughout the world. The USMS encompasses a diverse community of scientists, technologists, business professionals, and others in the workforce who work for companies, national laboratories, government agencies, universities, and trade and other organizations. Collectively and individually, they develop, supply, and/or support the continued value of measurement products, services, and infrastructure.

> Technology innovation is accelerated (from applied research to production, to market and end-use) by
>
> – Identification and communication of measurement needs
>
> – Measurement capabilities and technology that are currently available
>
> – Measurement innovation (including measurement technology development and commercialization)
>
> – Various non-measurement factors

Everyday, measurement problems are solved with currently available measurement capabilities and technology, and new measurement solutions are sought through R&D. Measurement R&D efforts focus on problem-solving and anticipating future needs and opportunities. For example, as new technologies, processes, and products enter the market, new measurement challenges are created.

Measurement innovation is fueled by scientific and technological breakthroughs and new ideas to bring together information and know-how in new ways. Continuous innovation in measurement science and technology is vital to technological advancement.

The USMS is part of the open economy where goods and services are developed and traded based on demand in the market. A multi-faceted set of scientific and technical skills and resources is required to provide the products, services, and infrastructure in this increasingly high-tech business. Because of the unique nature of measurement science, how measurement supports commerce, and the high costs of some measurement technology, a U.S. national measurement institute (namely NIST) is required to support strategic aspects of the USMS.

Process Used to Develop the Characterization

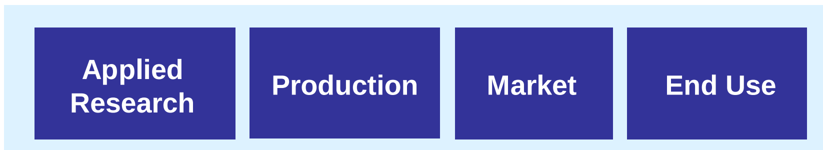
The Team set out to describe the USMS; to develop a logical, defendable, easy-to-understand framework (structure) for analyzing and communicating about how USMS contributes to technological innovation (TI); to help explain the impact of the measurement needs in the MNs and roadmaps; and to help assess the state of the USMS. The exhibits presented in this appendix are the results from brainstorming and in-depth discussion with the Team. The exhibits are presented sequentially beginning on page 5. This information is provided for consideration and use in the development of the USMS Assessment.

Results from Brainstorming and Discussion

Exhibit A1 lists the definitions of terms used in this appendix. Exhibit A2 lists the stakeholders of the USMS, and Exhibit A3 lists the diverse responsibilities of the USMS that have been considered.

In the current measurement needs assessment, the focus is on identifying where the lack of measurement capability constitutes a significant barrier to TI. The four stages of TI for products and processes are defined as applied research, production, market, and end-use. Applied research is aimed at realizing a new product-process technology. The applied research stage results in a prototype design, which is scaled-up and produced ready for sale in the production stage. During the market stage, sale and distribution are enabled by the development of marketing infrastructures. The end-use stage occurs after sales occur and problems are identified during use.

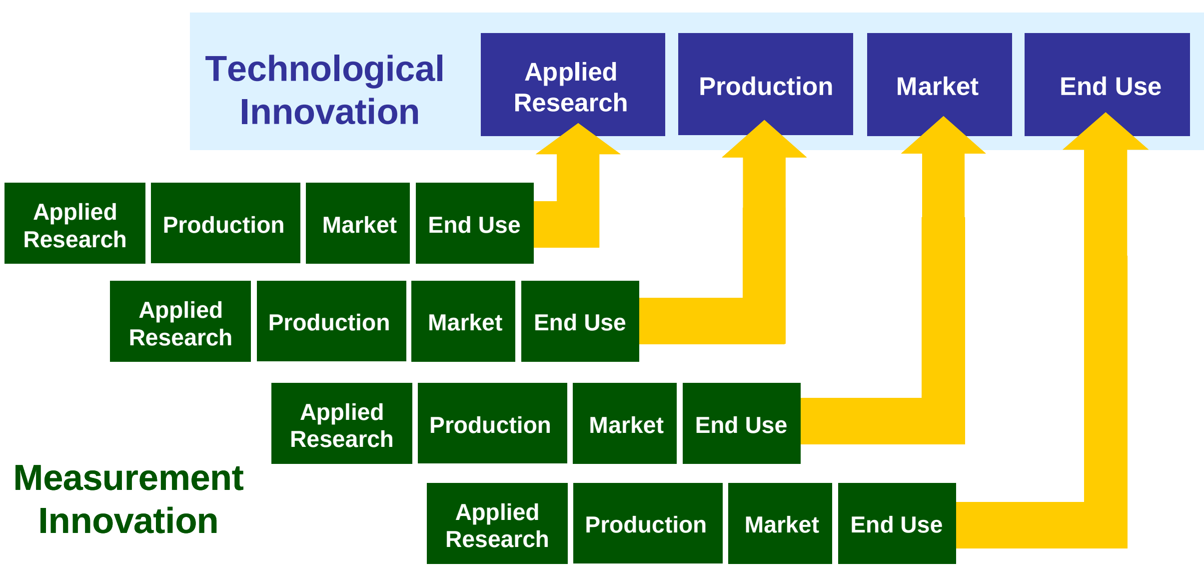
Four Stages of Technological Innovation



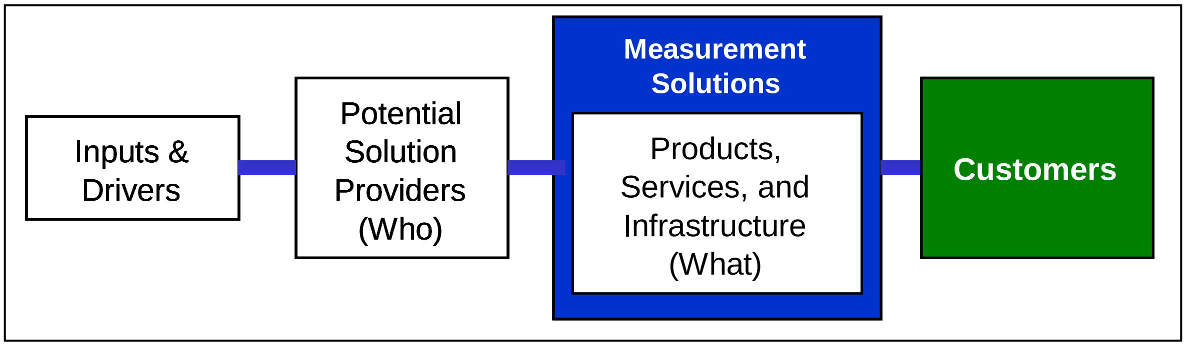
Measurement needs exist at each stage of TI, and many of these needs require measurement innovation. The drivers and barriers to measurement innovation vary by the stage of TI. They are both science-based and related to market economics. Exhibit A4 presents the drivers and barriers for TI that typically exist in applied research (only). Exhibit A5 presents the drivers of measurement innovation at each stage, and Exhibit A6 presents the barriers to measurement innovation at each stage. The issues faced during measurement solution development are often different depending on the stage of TI. Exhibit A7 summarizes some of these differences. There are also commonalities across the four stages and they are summarized in Exhibit A8.

To meet a customer's measurement needs at each stage of TI and overcome measurement barriers, measurement problem-solving and innovation must take place. The stages of measurement innovation can be described analogously to the TI stages as shown below.

The Four Stages for Measurement Innovation Support Technological Innovation



At different TI stages, a range of measurement solutions are often needed and some measurement solutions are unique to the stage. Different types/combinations of solution providers provide each measurement solution. In other words, the types of measurement products, services, and infrastructure (i.e., the measurement solutions) needed can vary by the stage of TI. The measurement inputs and drivers, solution providers, and solutions are identified for the customers at each stage of TI in Exhibits A9, A10, A11, and A12. These exhibits provide a profile of "who does what for whom," as illustrated below.



In the applied research stage, measurement innovation helps overcome barriers to development of a prototype design. In production, measurement innovation is used to help with scale-up. In the market stage, measurement innovation can help over come a barrier to market development and the purchasing process. In the end-use stage, measurement innovation can help resolve disputes of claims that are reactions in the market, such as an unanticipated outcome.

Technological innovation starts with a developer's vision of what to create. This vision is inspired by a problem or opportunity. Along the development pathway, measurement and other barriers must be overcome. Developers have to consider how a TI will function within a system. For example, at the end-use stage, a system's requirements may change due to another developer's technology innovation (e.g., a stronger vest for more powerful bullets). As a technology innovation enters the market, it can spur the need or opportunity for a new developer's vision. Measurement innovation also starts with a developer's vision.

Many factors contribute to measurement problem-solving and innovation. Some of these factors are presented in Exhibit A15. Some of these factors can be used as indicators of measurement-related activity, as shown in Exhibit A16. Measurement problem-solving and innovation contribute significantly to TI. The major categories of contribution include understanding, communication, controlling, manufacturing, trading, verifying, and determining performance. The solution providers needed to spur measurement innovation are diverse, requiring science, engineering, and many other areas of expertise.

If a measurement solution to a measurement problem does not exist, measurement innovation is needed.

Exhibit A1. Definition of Key Terms Used in this Appendix

Definitions

Customers of measurement solutions are diverse. Technology developers are an important customer to spur technology innovation. Major categories of customers include:

- Technology developers
- Consumers/technology users
- Suppliers of information for technology developers and consumers/technology users
- Advocates of consumers/technology users
- Regulatory agencies

Developer's vision for a technology spurs technological innovation. Achieving the vision may require measurement problem-solving and innovation.

Measurands are the properties and characteristics that measurement technology seeks to describe. The major categories of measurands include:

Functional
- Acoustical
- Electronic/electrical
- Magnetic
- Optical
- Photonic
- Radio frequency
- Thermal
  - Thermochemical
  - Thermodynamic
  - Thermophysical

Structural
- Mechanical
- Spatial
- Kinetic
- Molecular

Chemical
- Biological
- Chemical
- Physical
- Physiological

Performance
- Computational Performance
- Software Performance
- System Performance

Measurement is the result of a quantitative process to compare a variable characteristic, property, or attribute of a substance, object, or system to some norm, effectively a standard. Producing a measurement often requires a combination of measurement methods, instruments, entities, and standards as well as people and institutions.

Measurement innovation is the development of a new measurement solution that did not exist before. Measurement innovation can result in the development of new measurement technology, products, and services (i.e., technology innovation focused on measurement).

Measurement problem-solving can be achieved with currently available measurement capabilities and technology.

Measurement solutions are the metrology products, services, and infrastructure. They solve measurement problems and often require measurement innovation. The following are major categories of measurement solutions:

Products
- Measurement instrument
- Measurement method
- Software
- Computational method or models (validated)
- Calibration method
- Raw properties data
- Validated (hardened) properties data
- Test methods for production-scale measurements
- Test methods or test data for consumer products
- Standard/certified reference material

Services
- Calibration service
- Expert consultation
- Third-party verification/validation
- International recognition

Infrastructure
- Data collection and retrieval systems
- Standards
- Protocols
- User facility
- Coordination/facilitation
- Fundamental scientific knowledge

Exhibit A1. Definition of Key Terms Used in this Appendix, *continued*

- Stability tests (interim check stand)
- Reference data
- Metrics / Benchmarks
- Development for measurement technology

Potential measurement solution providers are the measurement science and technology developers, producers, and suppliers that provide the products, services, and infrastructure. The following are major categories of potential measurement solution providers:

- National Measurement Institute
- Government laboratories and agencies
- Independent testing/certification laboratories
- Calibration laboratories
- Commercial calibration service providers
- Testing laboratories
- Contractor R&D labs-for-hire
- Universities
- Software developers
- Industrial R&D laboratories
- Small business/inventors
- Instrument suppliers
- Component suppliers
- Material suppliers
- Standards development organizations (SDO)
- Engineering management/consulting firms/A&E firms
- Industry consortium/ partnership

Measurement solution providers develop measurement solutions for customers, and some measurement solutions are incorporated into measurement technology. For this document, measurement providers can also be measurement technology developers, and the challenges of manufacturing are similar to many other technology developers. Technology developers are an important customer.

Measurement system is an arrangement combining measurement science and technology to measure something of interest to a customer's specifications; for example, combining several measurement components with data to achieve a specific application capability.

Measurement technology is the measurement expertise and equipment needed to produce a measurement.

Solution providers—see measurement solution providers.

Technology developers often need measurement solutions to spur technology innovation. Technology developers are an important customer of measurement solutions, but there are other kinds of customers as well. Some technology developers can find measurement solutions within their own organization.

Technology innovation is defined in this study as the introduction of a new technology into the marketplace. Measurement problem-solving and measurement innovation often are required for technology innovation. The four stages of technology innovation are applied research, production, market, and end-use.

U.S. Measurement System (USMS) provides and applies metrology products, services, and infrastructure to support R&D, commerce, and consumer interests.

Exhibit A2. Stakeholders of the U.S. Measurement System

End-Users	Science and Technology Community	Trade Associations	User Groups (constituencies)	Advisory Group
▪ Suppliers ▪ OEMs ▪ Consumers/ buyers ▪ Industrial users (manufacturers) ▪ U.S. citizens who benefited/impacted by health of USMS; public good is served by fairness and accuracy ▪ Everyone who – makes measurements – uses measurement results – is impacted by measurement results – is affected by use of products	▪ Basic and anticipatory research ▪ Universities ▪ National laboratories ▪ Industrial R&D labs ▪ Roadmap development teams ▪ Technical consortia	▪ Represent groups of corporate entities ▪ Serve to define multidisciplinary areas ▪ Serve as main source of information for smaller businesses ▪ Communication portals, conduit for news and information ▪ Represent disciplines (AIcHE, etc.) ▪ Access/networking across groups/ industries ▪ Critical mass for opinion/validation of needs ▪ Representative of their affinity ▪ Provide one proprietary information – impetus for formation of consortia ▪ Consensus builders/facilitators ▪ Participate/provide input to standards organizations (ASME Press boiler) ▪ Develop industry positions and roadmaps ▪ Lobby and influence funding agencies ▪ Function as defacto standard developers	▪ Measurement instrument users ▪ IT user groups	▪ Healthcare/patient advocacy groups ▪ Socially conscious groups (includes environmental) ▪ Organized labor

Exhibit A2. Stakeholders of the U.S. Measurement System, *continued*		
Standards Development Organizations (SDO)	**Measurement Laboratories**	**Laboratory Accreditation Bodies**
▪ Two types of standards organizations: – Product function testing/characterization of performance – ASTM test materials inputs to R&D, products, test method development ▪ Consider implications of standards (reactionary and slow; can get bogged down with process) ▪ Well-established metrologies ▪ Technology innovation drivers; agree on standards that lead to next generation technology ▪ Facilitate technology adoption ▪ Represent both providers and users of standards to build consensus ▪ International – More political considerations in building consensus – More non-technical issues that impact consensus ▪ NIST writes standard – FIP (federal information protocols) – ITL (information technology lab)	▪ NIST – calibration, Standard Reference Material (SRM) and Standard Reference Data (SRD) ▪ Calibration labs of national labs ▪ Commercial calibration labs ▪ Commercial testing labs (U.L.) ▪ Credited Reference Material (CRM) manufacturers	▪ National Validation Laboratories (NVLAP) ▪ American Association of Lab Accreditation (A2LA) ▪ Multiple other bodies in different fields

Exhibit A2. Stakeholders of the U.S. Measurement System, *continued*

<table>
<tr><th colspan="2">Regulatory Agencies/Bodies
(force of law)</th><th rowspan="2">Private Entities
(These entities make but do not enforce product code; their codes are voluntary but are often used as the basis of enforced codes)</th><th rowspan="2">International Organizations and Foreign Government</th><th rowspan="2">Congress</th></tr>
<tr><th>State, Local, & Municipal Government</th><th>Formal Government Agencies</th></tr>
<tr><td>▪ Building code organizations
▪ National conference of weights and measurements (NCWM) (state oversight)</td><td>▪ EPA
▪ Nuclear Regulatory Commission
▪ FDA
▪ OSHA
▪ DOE
▪ FCC
▪ FAA
▪ Federal Trade Commission
▪ Others</td><td>▪ Underwriters Laboratory (UL)
▪ Factory mutual (fire rating)
▪ National Electrical Manufacturing Association (NEMA)
▪ Force of law and force of contact as a result of adoption by trade associations, e.g., ASME boiler codes</td><td>▪ Impacts/barriers to trade
▪ Joint calibration
▪ Standard development organizations (SDOs)
▪ EU trading block
▪ Regulatory issues</td><td>▪ Has vested interest in economy and welfare of citizens</td></tr>
</table>

Exhibit A3. Proposed Purpose and Description of the U.S. Measurement System

Purpose of the USMS

- Deliver valid measurements for a common purpose
- Deliver valid measurements that meet the economic needs of U.S. citizens in business, commerce, trade, health care, government, defense, or any other aspect of life
- Develops, supplies, and/or supports the continued value of measurement products, services, and infrastructure
- Provides solutions to measurement problems and measurement innovation
- Solves problems and anticipates future needs and opportunities
- Problem-solving through measurement innovation leads to new measurement goods and services
- Provides accurate, reliable, and accepted measurements that are vital to R&D progress, commerce, and consumer interests throughout the world

Description (Parts) of the USMS

- A complex of all the people and institutions, private and public, in the United States that make, use, or serve to insure the validity of measurements carried out for economic purposes as well as the technical means they employ
- Combination of technical elements, people, institutions aimed to produce valid measurement results for a common purpose
- Encompasses a diverse community of scientists, technologists, business professionals, and others in the workforce
- Companies, national laboratories, government agencies, universities, and trade and other organizations, and individuals
- Supports technological innovation
- Uses scientific and technological breakthroughs and new ideas to bring together information and know-how in new ways R&D efforts focus on that part of the open economy where goods and services are developed and traded based on demand in the market
- Utilizes a multi-faceted set of scientific and technical skills and resources in an increasingly high-tech business
- Supported strategically by a U.S. national measurement institute (namely NIST) because of the unique nature of measurement science, how measurement supports commerce, and the high costs of some measurement technology
- Infrastructure that supports the measurement innovation economy
- Total national enterprise engaged in measurement
- Dynamic interconnections and give-and-take

Exhibit A4. Drivers and Barriers in Applied Research

Drivers of Applied Research	Barriers to Applied Research
▪ Serendipity – discovery leads to product development ▪ Desire to create a new "toy" – scientific curiosity ▪ Finding a "home" for multi-disciplinary technologies ▪ Student/genius interest – appeal of science – human capital response ▪ Popularity of "science of the day" – what's in fashion ▪ Performance assessment of staff is a personnel motivator ▪ Early technical success to "make the case" to proceed – validation of developer's vision ▪ Infrastructure to answer questions needed to evaluate innovation (e.g., Bill of Materials) ▪ Emerging discoveries that lead to formation of promising technology "clusters" ▪ Breakthrough technology, feasibility known – potential to exploit what is known – venture capitalist interest ▪ Emerging clusters of knowledge in the literature (high visibility to funders) ▪ Multiple drivers form a critical mass – nexus of different things coming together (breakthrough, clusters, funding, etc.) ▪ Business opportunity ▪ Return on investment (ROI) ▪ Cost reduction ▪ Improved functionality ▪ Regulatory and safety compliance; improved quality of life ▪ Development of competitive products/keeping up with the competition ▪ "Buy-in" of advocate (internal or external, i.e., there is already a customer ▪ Societal disasters and terrorism; uncontrolled vs. controlled problems ▪ Societal benefits and needs ▪ Time-to-market	▪ Nature – It's not possible ▪ Absence of critical knowledge or technology ▪ Technical risk – approaching theoretical limits (low probability of success) ▪ Short time-to-market impedes R&D (insufficient time for R&D) ▪ Lack of funding ▪ Inability of scientist/researchers to effectively sell the technology to company/marketer ▪ Poor ROI – lack of business opportunity ▪ Lack of defined technology producer/partner ▪ Lack of acceptance/market leaders ▪ Company resistance to technology ▪ Lack of capability infrastructure ▪ Lack of information exchange ▪ Lack of acceptance

Exhibit A5. Drivers of Measurement Innovation at Each Stage of Technology Innovation

Applied Research	Production	Market Development	End Use
▪ Inability to measure something that is needed to achieve developer's vision – needs to be responsive – requires measurement capabilities beyond what exists ▪ Desire to solve a specific measurement problem (question) ▪ Quantitative data needed to develop a new technology ▪ Commonality of measurement needed across sectors – critical mass needs the tool ▪ Link phenomenon (or thing to be measured) and use for practical application (pragmatic) ▪ Value of a "better" something drives measurement development to meet needs in market	▪ Requirement for – ease-of-use – interoperability – speed of production – quality – efficiency ▪ Need for commercially available, hardened, proven, robust measurement technology ▪ Cost-effective measurements in the production environment ▪ Opportunities for new uses for existing technology ▪ Regulatory driver/response ▪ Inability to identify the "cause" so have to manage the effects and outcomes – need to know cause – default is pooling performance (effect), i.e., higher priced product ▪ New functionality achieved via measurement technology (relate value to use—may feedback to researchers to spur the developer's vision) ▪ Existence of roadmap defining critical needs in measurement technology ▪ Ability of competitor to demonstrate similar technology – market pressure	▪ Desire for product differentiation ▪ Customers are reluctant to purchase because they doubt claims ▪ Customers are dubious about performance—can expectations be met (not yet proven) ▪ Inability to prove claims (performance) ▪ Inability to demonstrate conformance to regulatory compliance	▪ Need for new standards/ regulation when products change (e.g., lead-free solder) ▪ Reference measurements, instruments, methods, etc. to compare different products/measurement methods ▪ Desire to convert an infrastructure (e.g., steel vs. aluminum bodies in autos) which requires adjustments to measurement ▪ Ability to measure security of electronic transactions ▪ Measurements needs are driven by product enhancements/changes ▪ Service support functions required by products/product changes (e.g., autos) – including products that are measuring devices (calibration labs) ▪ If product is a measurement instrument, calibration laboratories may be driven to develop techniques, etc. ▪ Complexity of parameters preventing ability to determine what needs to be measured ▪ Calibration needs for products ▪ High failure rate of product (end use drives production need) ▪ Inability to measure/prove performance to demonstrate that requirements are met ▪ Regulatory issues (e.g., ES&H) that arise because of a product

Exhibit A6. Barriers to Measurement Innovation at Each Stage of Technology Innovation

Applied Research	Production	Market Development	End Use
▪ Measurement science developments may be accelerated/ compromised to meet time requirements (not 100%) (measurement product/ process performance as an indicator of measurement capability that is not 100%) ▪ How it feeds into a "system" to provide value ▪ Measurement research takes longer than time needed for measurements by customers ▪ Not sure what question needs to be answered ▪ Lack of understanding of what needs to be developed ▪ Poor linkage between measurement need and innovation (researchers have not articulated "the case" for R&D) ▪ Difficulty explaining the value of the measurement to funding entities	▪ Difficulty reproducing measurements made in labs at production-scale manufacturing (off-line to in-line; issue of speed) ▪ Inability to transfer the technology from lab to production ▪ Inability to define life-cycle of product and then simulate via prototype measurement model ▪ Inability to tailor measurement technology/adapt know-how (slightly adapted or modified) ▪ Lack of understanding ▪ Lack of information exchange between diverse users ▪ Lack of computational capability (ability to analyze data) ▪ Proprietary needs limit access to protect intellectual property ownership	▪ Lack of a simple, cost-effective way to make a measurement to prove a claim ▪ Measurement technique has not been certified for use in measuring product characteristics	▪ [None listed]

Exhibit A7: Differences for Measurement Solution Development Across the Technology Innovation Stages

Description	Early/Front end	Late/Back end
Science/Mode	Theoretical; "nature" as explanation; anticipatory	Understood or empirically proven; reactive
Primary Motivation	Functionality and precision	Performance, quality
Definition of Success	Can you?	How many at what cost?
Measurement Costs as a Percent of Total Cost	Greatest in R&D	Measurement costs per product decreases
Focus of costs	Willingness to pay for knowledge, highly specialized skills and expert judgment	Return-on-investment
Timeline for Results	Longer	Shorter
Measurement and Data	Researchers are willing to tolerate ambiguity and mistakes; results are not codified; more flexibility	Hardened data and processes, "routinized," no ambiguity, codified, increased specificity, reduced to practices, procedural, simplification, limited flexibility Purpose and reasons are more narrow and more defined Measurement technology is more application-specific; more likely to be conducted by a company, and is largely proprietary
Operator Skill Requirement	Complicated calibration; amount of information is greater; dependent on expert judgment	Push a button to make it work; only want "this" and not "that;" decreased amount of information measured and managed; measurement must be easier
Measurement Users/Interested Parties Relative Mix	Scientists dominate; government more likely to be involved	Engineers dominate; financial institutions more likely to be involved
Motivation for Equipment Manufacturers	Niche market, few sales	More opportunities if the market expands

Exhibit A8. Commonalities for Measurement Solution Development Across the Technology Innovation Stages

- Desire to create technology that is faster, better, cheaper, and innovative
- Business case needs to be made, although it may change and be refined along the way
- Regulatory issues and concerns can be drivers and barriers
- Reliance on fundamentals to solve problems
- Quantitative data are essential (can't manage what can't be measured)
- Steady focus on improvement
- Developer's vision can be articulated
- An unmet need exists

Exhibit A9. Measurement Profile the for Applied Research Stage of Technology Innovation

Inputs/Drivers	Potential Solution Providers (Who)	Products, Services and Infrastructure (What)	Customers
▪ Scientific literature (new knowledge) ▪ Intellectual property ▪ High-tech application trickle-down/spill-over (shuttle to knife) ▪ A developer's vision due to a need, crisis, or opportunity, and possibly a prototype developer who implements the vision ▪ Specifications for – Reliability – Life prediction – Warranty issues – Maintenance – Service – Legal/regulation	▪ National laboratories ▪ Universities ▪ Industrial Labs – develop and use prototype – contract researchers to solve problems ▪ Small businesses/inventors	Software/Computational Capability	▪ Companies ▪ Group of companies ▪ Individuals ▪ Government agencies University and government labs were not included
	▪ National laboratories ▪ Universities ▪ Instrument vendors ▪ Contractor R&D labs-for-hire (Battelle, Lincoln Labs) ▪ Small businesses/inventors ▪ Components/materials from suppliers, both off-the-shelf as well as novel materials	Standard Reference Materials	
	▪ National laboratories ▪ Universities ▪ Industrial Labs – develop and use prototype – contract researchers to solve problems ▪ Small businesses/inventors	Prototype Measurement Test Method	
	▪ National laboratories ▪ Universities ▪ Industrial Labs – develop and use prototype – contract researchers to solve problems ▪ Small businesses/inventors ▪ Contractor R&D Labs-for-hire (Battelle, Lincoln Labs) ▪ Corporate R&D Labs ▪ Small businesses/inventors ▪ Components/materials from suppliers, both off-the-shelf as well as novel materials	Properties Data	

Exhibit A9. Measurement Profile the for Applied Research Stage of Technology Innovation, *continued*

Inputs/Drivers	Potential Solution Providers (Who)	Products, Services and Infrastructure (What)	Customers
	▪ National laboratories ▪ Universities ▪ Industrial Labs – develop and use prototype – contract researchers to solve problems ▪ Small businesses/inventors	Measurement Method and Instrumentation	
	▪ National laboratories ▪ Instrument vendors ▪ Industrial Labs – develop and use prototype – contract researchers to solve problems ▪ Small businesses/inventors	Calibration	
	▪ National laboratories ▪ Universities ▪ Industrial Labs – develop and use prototype – contract researchers to solve problems ▪ Contractor R&D labs-for-hire (Battelle, Lincoln Labs)	User Facilities	
	▪ National laboratories ▪ Instrument vendors ▪ Small businesses/inventors ▪ Components/materials from suppliers, both off-the-shelf as well as novel materials	Standards (artifacts)	
	▪ National laboratories ▪ Universities ▪ Software developers ▪ Instrument vendors ▪ Industrial Labs – develop and use prototype – contract researchers to solve problems ▪ Contractor R&D labs-for-hire (Battelle, Lincoln Labs) ▪ Small businesses/inventors	Expert Consultation	

Exhibit A10. Measurement Profile for the Production Stage of Technology Innovation

Inputs/Drivers	Potential Solution Providers (Who)	Products, Services and Infrastructure (What)	Customers
▪ TI "Prototype" from applied R&D ▪ TI Developer's Vision ▪ Product design specifications for measurement device (develop MI vision) ▪ Existing measurement capability that requires further innovation to achieve ▪ Robustness (e.g., independent of operator, science rather than "art," etc.) ▪ Better, faster, cheaper (e.g., 10x performance) ▪ Commonly used standards ▪ Interoperability ▪ Standard practice for part of the solution ▪ Engineering concepts in engineering research literature/other sources ▪ Intellectual property ▪ High tech trickle-down/spill-over ▪ Feedback from users of current measurement technologies (history, experience, technique) ▪ New materials and material property innovations ▪ Proprietary know-how ▪ Anticipated problems in quality, yield, reliability of production process, e.g., operability bottle-necks	▪ Independent re-certification labs (sell services) ▪ Commercial calibration service providers (sell product)	Calibration of physical standards aimed at production level	▪ Companies ▪ Group of companies ▪ Individuals ▪ Government agencies
	▪ Specialized A&E	Specialized metrology user facilities (clean rooms, vibration isolation rooms, etc.)	
	▪ Commercial standards producers	Calibration artifacts and certified reference material	
	▪ Manufacturers of off-line and in-line measurement tools	Measurement hardware (e.g., instrument that performs a measurement)	
	▪ Developers of processes/ data measurements for uncertainty (measurement product vs. process)	Methods, methodologies, and techniques	
	▪ Engineering and management consulting firms ▪ Individual consultants ▪ National lab/university/other measurement developers	Expert consultation (advise on why specs aren't met, etc.)	
	▪ Commercial providers ▪ National labs (e.g., data to support mass spec) ▪ Corporate in-house proprietary data providers	Validated, tested (hardened) data evaluated at a greater level of reliability	
	▪ How to use measurement implements to transfer material-methods particularly, doable and procedural	Measurement test methods accepted by customers (commercially hardened)	
	▪ Commercial measurement software providers	User friendly software and models-processes-specific, turn-key, mistake proof; could be a module	

Exhibit A11. Measurement Profile for the Market Stage of Technology Innovation

Inputs/Drivers	Potential Solution Providers (Who)	Products, Services and Infrastructure (What)	Customers
▪ Feedback and concerns (e.g., storage, handling, distributor issues) ▪ Need for impartiality to substantiate a claim ▪ Regulation concerns – new or proposed	▪ Industrial R&D laboratories ▪ Independent testing/certification laboratories ▪ National laboratories ▪ NMI ▪ Other government ▪ Component suppliers ▪ Material suppliers ▪ Instrument suppliers	▪ Standard/certified reference material ▪ Measurement method ▪ Measurement instrument	▪ Producer or product user who needs validated documentation of enhanced product characteristics ▪ Producer or product user who needs a measurement ▪ Regulatory agencies

Exhibit A12. Measurement Profile for the End-use Stage Supporting Technology Use

Inputs/Drivers	Potential Solution Providers (Who)	Products, Services and Infrastructure (What)	Customers
Producer concerned about an unexpected or changed conditions of use of a product in customers' hands; warranty issues, after-sales service, liability	▪ Independent testing laboratories ▪ Contract R&D ▪ Labs (commercial, government or university) ▪ Developers of test methods and calibrations that are used by others	▪ Higher accuracy calibration service or technique ▪ New calibration service, e.g., angular acceleration crash testing on cars and better dashboard lights	▪ Producer of goods
Concerns of customer-marketplace for product functionality, reliability, safety	▪ Independent testing laboratories (including Consumer Reports)	▪ Test methods for consumer products ▪ Innovative set of test data on a consumer product; it is used to influence a consumer decision	▪ Consumer-representation organization, e.g., consumers union ▪ Consumers of products ▪ Commercial user of products ▪ Producer of goods
Regulations, actually or potentially to be, introduced after product introduction	▪ Independent testing laboratories ▪ Contract R&D ▪ Labs (commercial, government or university) ▪ Consumer Product Safety Commission (do they do method development?)	▪ Measurements and standards to meet new regulations – reference material – standards – test methods – calibration methods	▪ Regulatory bodies ▪ Producer of goods to be compliant
Need for cost-effective calibration	▪ Metrology R&D labs for the artifact standards ▪ SDOs for documentary standards	▪ Interim check stand (new); this is a stability test, not an absolute value test, i.e., that it has not changed	▪ Purchaser of technology (possibly but not necessarily a measurement device) who wants to ensure that it stays in calibration, i.e., goal is to validate functionality in continued use

Exhibit A13. Factors Contributing to Measurement Problem-Solving and Innovation

Availability & Accessibility	Utility	Competitiveness Orientation
Ability to meet conventional measurement needs & provide timely, cost-effective solutions	Ability to use and gain value from measurement solutions	Ability to meet both domestic and global measurement needs and to ensure U.S. products are competitive in international markets
▪ Technology developers are aware of the measurement solutions that exist to solve problems ▪ Technology developers know how to pursue measurement innovations to meet emerging needs ▪ Solutions and solution providers (including product and service support) can be – Identified with ease and expediency – Available when needed to meet the needs of an R&D planning horizon – Acquired with few or no procedural barriers – Purchased/hired at an acceptable price (and not held as proprietary) ▪ Measurement scientists and technologists are entering the workforce in sufficient numbers to satisfy demand	▪ To support technology development, measurement solutions can be – Clearly understood to assess value for new applications – Applied to solve problems cost effectively – Applied by technicians without advanced degrees (based on user friendliness) – Transferred effectively and integrated/engineered for an application (e.g., from a predictive model to an improved production line) – Used without infringing upon proprietary considerations – Developed with an acceptable return on investment – Sold convincingly to those who make decisions on R&D investment and purchasing – Demonstrated and compared – Approved and certified for use by application area – Analyzed using computational capabilities	▪ Measurement solutions contribute to technology development, especially to solve urgent problems and enhance competitiveness in economically significant areas ▪ Measurement solutions are able to contribute to process and product competitiveness by – Accelerating production – Reducing production costs – Reducing product costs – Improving production process and product quality – Creating new processes and products ▪ Measurement providers compete in a national and worldwide market ▪ Measurement providers participate in forums worldwide to advance measurement science and technology ▪ International standards, mutual recognition arrangements, and laboratory accreditation enable global compatibility and promote commerce ▪ New measurement knowledge and measurement technology are tracked worldwide and used ▪ Government policies support measurement innovation

Exhibit A13. Factors Contributing to Measurement Problem-Solving and Innovation, *continued*

Innovation Orientation
Ability to anticipate needs, rise to meet emerging needs, and provide measurements that spur innovation

From Technology Developers' Perspective	From Measurement Solution Providers' Perspective	Other Issues
▪ Technology developers anticipate measurement needs and solve measurement problems before they become an obstacle to technological innovation ▪ Technology developers have the financial resources to purchase or develop measurement solutions so they need not work around them ▪ Technology developers effectively communicate measurement needs to measurement providers and the scientific community through meetings and publications (e.g., roadmaps) ▪ Scientific breakthroughs impacting metrology are rapidly communicated to technology developers in public documents and conferences ▪ Technology developers in different sectors/disciplines with analogous measurement needs can: – Recognize their common needs – Support a shared path to develop solutions	▪ Measurement solution providers have the ability to identify and understand the measurement needs, performance specifications, and expectations of technology developers by – Conducting needs assessments with end users – Participating in professional societies – Attending conferences and meetings – Reading industry roadmaps, journals, and other publications – Tracking technology development and use, which can lead to new measurement needs – Tracking new legislation that can require new measurement solutions ▪ Measurement providers are able to convincingly communicate the value of measurement R&D ▪ Measurement providers are able to rapidly incorporate measurement innovations in the manufacture of new measurement solutions (i.e., moving the innovation from the lab into commercial production) ▪ Measurement providers sell continuously more precise and reliable measurement tools and services to support technology innovation, especially in emerging technological areas	▪ Technology developers, basic/applied science and technology researchers, and measurement providers share a vernacular that enhances clear communication of measurement needs and solutions ▪ Basic and applied researchers anticipate measurement needs of technology developers and push the leading edge of measurement capabilities ▪ Scientific breakthroughs impacting metrology are rapidly communicated to measurement providers in public documents and conferences to enable next-generation measurement solutions ▪ Progress in measurement innovation is indicated by the number of relevant – Publications – Patents – Measurement-enabled product differentiation, new products, and new components in products – New measurement providers – Competing solutions to measurement problems

Exhibit A14. Indicators for the Measurement Needs Analysis			
Availability & Accessibility	**Usability**	**Competitiveness**	**Innovation Orientation**
▪ # of needs identified in roadmaps that have known solutions Requiring published information or follow-up: ▪ Yes/no/describe: For the needs identified in roadmaps, have the technology developers/ customers pursed solutions? ▪ Yes/no/describe: For the needs identified in MNs, have the technology developers/ customers pursed solutions? ▪ # of measurement scientists and technologist entering the workforce verse the # retiring compared to the rate of increase in demand	▪ # of RMNs and MNs that identified a need for integration/ engineering of known measurement capabilities into an application ▪ # of RMNs and MNs that identify a need for acceptability and certification	Requiring published information or follow-up: ▪ Case study of how a measurement solution contributed to technology development to solve an urgent problem and in a critical economic area	▪ # of MNs with a need identified in a roadmap ▪ # of needs identified in both the roadmaps and the MNs Requiring published information or follow-up: ▪ Case study of new measurement-enabled product differentiation, new product, and new component in a product ▪ # measurement publications ▪ # new patents ▪ # new standards ▪ # new measurement products/services ▪ # new measurement providers ▪ # conferences/meetings informing measurement providers of scientific breakthroughs ▪ # conferences/meetings informing technology developers of measurement science and technology breakthroughs ▪ # of technology developers who are aware that they have measurement needs that are in common with other sectors

APPENDIX B

Directions for the Inferential Analysis Workshops

Introduction to the Café

Overview

The inferential analysis will focus on 11 sectors/areas. A café-style setup will be used (see below); Energetics will facilitate the process step-by-step following the agenda.

Setup:

- 5-6 tables, one for each sector/area
- 3-4 team members assigned to each sector/area (per table)
- 1 laptop for information collection per table
- 1 laptop for searching information

Process:

Six sectors/areas will be analyzed the first day, and five the next day. A NIST team of three to four people will be assigned to each sector/area to analyze the data. The teams will work concurrently, answering the same questions but on different topics. Each team will have data/information specific to their sector/area at their café table, as well as access to data/information from the other groups. The facilitators will guide the process and help to identify synergies between groups.

The team leads will capture the conclusions of their group on their laptop computer in real-time. The facilitator will keep time and circulate to trouble shoot. Periodically, each group will share the specific type of questions they answered, so the other groups will have an opportunity to consider this in their own analysis. When a section is completed, the results will be printed out and reviewed by the facilitators. At the end of the second day, everyone will have a copy of the analysis from each group to review. One more day will be allowed to integrate comments before the complete set is edited to have "one voice."

Advantages of café process:

- Expedites the inferential process and allows time for the team to review all sectors/areas
- Creates momentum for analysis
- Enhances continuity across sectors/areas and builds understanding for everyone
- Synergies are identified across sectors/areas in real-time

Directions

The sector/area Chair and at least one other member will need to bring a laptop computer with the following capabilities: (1) Word, (2) Excel, (3) Access, (4) wireless web-enabled, and (5) a working USB port for memory stick information exchange.

In advance of the Inferential Analysis Café, each team member should consider how to answer the questions listed on the agenda, and review the information listed below.

1. USMS Technology Roadmap Review
2. USMS Measurement Need (MN) Data Book
3. MNs relevant to sector/area(s)
4. MN and RMN Excel spreadsheets
5. Preliminary characterization of the USMS
6. Other information/data sources

The Inferential Analysis Template on the next page will provide continuity of presentation for each sector/area. The Input Templates (blue sheets) are to be filled out in advance; if typed, please bring an electronic copy and hardcopies to share with the other team members. A customized electronic template of the *Inferential Analysis of Measurement Needs: A Workshop Report* will be provided to each team at the start of the workshop. As consensus is reached, fill in the templates for each round (i.e., each team will write their section of the workshop report). Consider the following perspectives when answering each question:

- Technology developers (have the measurement need)
- End-users/customers (will benefit from resulting products/services)
- Measurement solution providers (develop and sell solutions)
- Federal government (promotes R&D, commerce, and consumer interests)
- Economic growth potential of the United States
- Potential and requirements for basic and applied science and technology development

The Inferential Analysis Template

The five rounds of questions in the Agenda will provide a structured way to analyze the data in each category and to present the results for each sector/area. Prior to the workshop, please review the data and note any issues that are surprising, confirming, or unexplained. At the workshop, each team will discuss these reactions.

For any data issues that a team considers significant, complete an *inferential analysis* using the template below. The template is intended to aide in quickly conducting a thorough inferential analysis. Start a new template for each major issue, focusing on the most important issues first. One inferential analysis may refer to 20 sub-categories of data or just one. After the workshop, the final "Findings" for the USMS assessment will be derived from these completed inferential analyses. Please write complete ideas, but do not spend time wordsmithing – this will be done after the workshop.

Inferential Analysis Template

Sector/Area______________
Round______ Letter ______Title__________________________

1. **Focus Area/Factual Statement**: Make a *brief* factual summary statement of the issue from the MN and RMN data. It is not necessary to explain in detail what can obviously be discerned from the data. Identify a "case study" to make a specific point.
2. **Interpretive Statement**: Make an interpretative statement (i.e., explain the significance of the data and what it means).
    - Support interpretations with information/data
    - Document assumptions
3. **Declarative Statement**: Make a declarative/speculative statement that may not be fully supported by the available data but could be further explored.
    - Support statements with information/data
    - Document assumptions
4. **Implications for the USMS**: Note how these statements impact the USMS or our understanding of the USMS. Explain.
5. **Question Parking Lot**: Inferring additional meaning from the data may require other information from experts or publications. List questions for further consideration/analysis.
6. **MN Exhibit # and page #**: List the exhibit number and page number in the *USMS MN Data Book*, 2006.
7. **RMN Exhibit # and page #**: List the exhibit number and page number in the *USMS Technology Roadmap Review*, 2006.
8. **References**: If you have referred to published information/data sources, please note the author(s), date, and page number(s). If you know of a publication that might provide insight, list it for future reference.

The Value and Limitations of the Measurement Need Data Sources

Two documents will serve as primary sources for the inferential analysis: the *USMS Technology Roadmap Review* (2006) and the *USMS Measurement Needs (MN) Data Book* (2006). Characteristics of the roadmaps and the MNs reviewed are listed below; please consider the value and limitations of the data when developing the inferential analysis. As noted in the next section, "Getting Started with the Inferential Analysis," some tag data available for the MNs are not available for the roadmap measurement needs (RMNs).

<u>Roadmaps</u>:

- Most are consensus documents
- Focus is on pre-competitive needs – ones industry will openly discuss – "proprietary" measurement needs are not represented
- Measurement needs are usually not the focus of the roadmap and measurement experts may not have contributed to the roadmap (with a couple of exceptions)
- Measurement needs listed are most likely:
  - A priority need
  - Aiming toward a technology innovation
  - A need not satisfied through a problem-solving network (e.g., vendors)
- Whether the measurement need has been satisfied already has not been determined
- Whether the measurement need is a focus of current R&D efforts has not been determined

<u>Measurement Needs (MNs)</u>:

- Developed by NIST and verified externally
- Focus on spurring technological innovation
- Focus on problems that are not satisfied through existing problem-solving networks (e.g., a solution does not exist today)
- Most are for pre-competitive needs in areas that are critically important to economic competitiveness or to solving social problems
- NIST is confident that MNs exist today

Getting Started with the Inferential Analysis

The MN data will be tagged in 12 categories, (see the MN Tagging Assumptions) and tabulated. Distributions and cross tabulations will be presented in a report titled *USMS MN Data Book, 2006*, which will serve as the primary source of data for the inferential analysis. The categories are listed below with descriptions and teaser questions to help start the inferential analysis, and may help identify meaningful cross-linkages among the categories.

Data from the *USMS Technology Roadmap Review, 2006*, is also available for categories 1, 2, 6, and 8 (short list). The data source available for the analysis (MN and RMN) is identified for each category in parentheses. Multiple tags (up to three) are possible for the MN categories 1, 2, 3, 7, 8, 9, 10, and 11.

#1. NIST Sector/Technology Area (MN and RMN)
A sector area will benefit from technological innovation. The technology developer may be the sector itself (the one with the vision and the measurement need), or a supplier to a sector (e.g., a technology developer envisions a better component to meet a sector's specifications). For each sector, consider how technology development needs and specifications are met (by the sector itself or by the supplier).

Teaser Questions:

- What stage of technology innovation (#4) do the measurement needs fall into?
- What percentage of MNs requires measurement technology innovation (#5)?
- What measurement needs exist, per the measurand (#8)?
- What are the measurement barriers (#9)?
- Who are the potential solution providers (#11), and with whom do they interact?
- Is the technology developer a supplier meeting an end-user's specifications? Do they have their own vision for providing an innovative product/service?
- How is measurement impeding technological innovation?

#2. NAICS (MN and RMN)
This tag will not be considered in the Inferential Analysis Café.

#3. NIST Basis (MN)
The NIST Basis can be used internally to track the MNs that have been tagged and identify cross linkages across MN focus areas/perspectives. Some sub-categorizations are redundant with other categories that may be more helpful for inferential analysis. *This tag will not be considered in the Inferential Analysis Café.*

#4. Stage of Technology Innovation (MN)
Different challenges are faced at different stages of technological innovation. For example, different stages may have different barriers to measurement, may be served by different solution providers, may require different types of solutions, and/or face different measurand challenges. While some measurement solutions are used across the stages of technological innovation, some measurement solutions are specific to a stage.

Teaser Questions:

- How do the barriers (#9) vary?
- How do the solutions (#10) vary?
- What potential solution providers (#11) are most often involved?

#5. Is the technological innovation at stake a measurement technology? (MN)

Technological innovation is supported by existing measurement capabilities as well as measurement innovation. The focus of the MNs and RMNs are measurement needs that require measurement innovation (i.e., where barriers exist that cannot be solved today). Measurement innovation may or may not result in a new measurement technology that can enter the market.

Teaser Questions:

- What types of measurement solutions (#10) never become measurement technologies? What solutions are "packaged" as a new measurement technology?
- What potential solution providers (#11) develop what kind of measurement technology? Do potential solution providers develop and sell to a specific niche (i.e., sector)?

#6. Regulation as a driver or barrier (MN and RMN)

Regulations act as drivers or barriers to measurement R&D. New regulations can create a need for new measurement capabilities, and measurement needs can overcome a regulatory barrier that is preventing a technology innovation from entering the market.

Teaser Questions:

- What types of measurement solutions (#10) are needed as a result of a regulatory driver or barrier?
- Based on the MN data, how much measurement innovation is driven by a regulation impacting technology development/innovation?

#7. Effort in Progress—Public and/or Private (MN)

This tag distinguishes R&D conducted by the government from R&D conducted by the private sector. This can be used delineate between what companies are investing in and what the government is investing in. If neither public nor private is selected, this would indicate that no efforts to support this technology innovation are currently in progress.

Teaser Questions:

- In what areas are both the public sector and the private sector pursuing R&D?
- What types of measurement barriers (#9) are not currently being pursued by either the public or private sector?
- What types of measurement solutions (#10) are being explored by the private sector and not by the public sector and vice versa?

#8. Measurand (MN and RMN-short list)

The measurand is a proxy for the types of measurement needs that exist. Sub-categorizations by measurand can be used to identify synergies across research areas.

Teaser Questions:

- What relationships exist among needs with the same measurand?
- What is the distribution by stage of technology innovation (#4) and effort in progress (#7) for each measurand?
- For each measurand, what measurement barriers (#9) occur most often?
- For each measurand, what measurement solutions (#10) are needed most?

#9. Measurement Solution Barrier (MN)
Barriers to measurement innovation are often barriers to technological innovation. The barriers to developing new measurement solutions reveal the nature of the problem that must be overcome, and can be used as a proxy for the types of measurement needs that exist. The measurement solution barrier can be used to identify if a market failure exists that is impeding measurement innovation and/or if the nature of measurement science and technology is impeding measurement innovation.

Teaser Questions:

- What commonalities and differences exist among the MNs with respect to each barrier?
- What types of barriers require government assistance to overcome?
- How do barriers vary by stage of the technological innovation (#5)?
- For each barrier, what type of assistance/solution (#10) or potential solution provider (#11) is needed?

#10. Measurement Solution (MN)
Measurement solutions are the products, services, and infrastructure that will overcome a barrier to technological innovation at a specific stage. Measurement solutions are targeted to a specific set of measurands for a specific application. Many are customized for each application, and some can eventually become “off-the-shelf.” Some measurement solutions will most likely not be developed unless there is government involvement, and some require collaboration among a user community.

Teaser Questions:

- For each type of measurement solution, what types of efforts are in progress (#7)?
- What measurands (#8) need to be addressed?
- What measurement barriers (#9) have to be overcome?
- What potential solution providers (#11) could be involved?

#11. Potential Solution Providers (MN)
Solution providers are in the business of solving measurement problems. Individually, they provide one or more products or services.

Teaser Questions:

- For each type of solution provider, what efforts are in progress (#7)?
- What measurand (#8) are they focused on most often?
- What barriers (#9) do they overcome?
- What types of measurement solutions (#10) do they provide?